MECHANICAL DESIGN OF RFQ RESONATOR CAVITIES IN THE 400-MHz FREQUENCY RANGE*

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Summary

Many RFQ resonator-cavity design concepts have been proposed in the 400-MHz frequency range. Los Alamos has been evaluating RFQ resonator-cavity designs that provide acceptable combinations of necessary mechanical features, easy tunability and long-term stability. Four RFQ resonator test cavities have been fabricated to test rf joints between the RFQ vanes and the resonator cavity. Two of these joints (the C-seal and the rf clamp-joint) allow vane movement for tuning. These test data, and the design of the present generation of RFQ resonator cavities, are presented.

Introduction

The general configuration of the RFQ linac consists of four specially machined vanes mounted within a cavity. This cavity is both a mechanical support for the vanes and an rf resonant cavity. Experience with the all-copper 425-MHz RFQ POP linac (Fig. 1) has shown that the resonator cavity must be easily tunable and structurally stable to maintain the tuning.[1] Seven desirable RFQ resonator cavity design criteria have been identified:

(1) adequate structural stability,
(2) low fabrication costs,
(3) adequate cooling,
(4) simple assembly techniques,
(5) an acceptable cavity Q,
(6) ease of tuning, and
(7) long-term stability.

RFQ resonator-cavity design is an optimization process, trading off relative advantages and disadvantages between these criteria.

The rf fields in an RFQ resonator cavity run axially between the vanes in the quadrant, circling the end of each vane to connect fields in the adjacent quadrants. The rf currents flow from vane to vane across the interior of the resonator cavity,

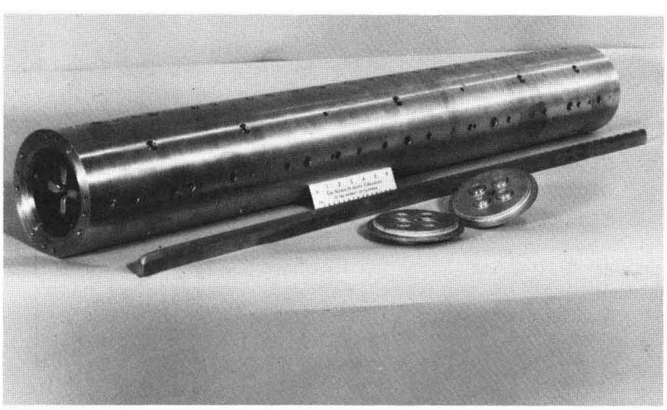

Fig. 1. The 425-MHz RFQ POP resonator cavity.

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as shown in Fig. 2. The rf requirements for frequencies in the 400-MHz range are

- magnetic field equal in each quadrant to ±2%;
- longitudinal magnetic field distribution flattened to within ±5%; and
- frequency adjusted to the required frequency, corrected for the dielectric constant of air and the operating temperature of the cavity.

The basic tuning methods[2] that may be used are

- machining inserts and/or moving tuners at the ends of each vane (varies the capacitance between the vanes and the cavity, and adjusts the axial electric field distribution);
- radially moving the vanes (primarily adjusts the frequency);
- circumferentially rocking the vanes (primarily alters the field distribution between quadrants);
- adjusting quadrant tuning slugs (tunes the frequency, balances the quadrant fields, and adjusts the longitudinal field distribution); and
- mechanically deforming the resonator cavity (simultaneously changes all tuning parameters).

Surrounding the resonator cavity is the RFQ power manifold (shown in Fig. 3) that supplies and distributes rf power to the RFQ linac. The rf power in the manifold drives the RFQ through diagonal rf coupling slots; these are typically ~1.6 cm wide, inclined at an angle of 30° to 45° from the orthogonal plane, and as long as possible to enhance the rf coupling. The cavity-wall thickness at the slot is relatively unimportant, provided that the slot width is at least equal to the wall thickness and less than ~10% of the slot length. The exterior of the resonator cavity should be fairly smooth, free of protrusions, so that the power manifold rf fields are not unduly perturbed. The performance of the RFQ linacs increases dramatically with higher surface fields; therefore, the vacuum required within the RFQ resonator cavity should be well into the 10^{-7} torr range to suppress sparking. The interior of the RFQ resonator cavity is pumped through the rf coupling slots to the RFQ manifold.

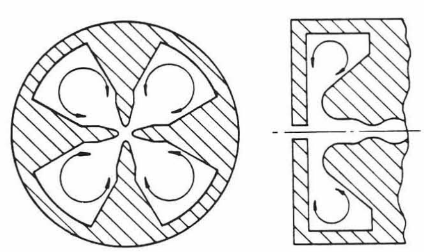

Fig. 2. The rf current flow within an RFQ resonator cavity.

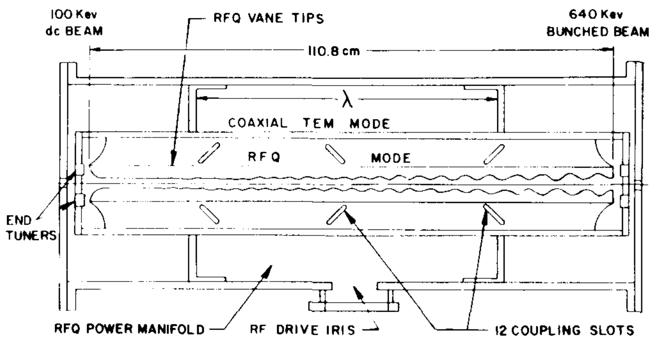

Fig. 3. RFQ POP linac schematic.

Schriber[3] has developed a formula for the rf loss (manifested primarily as structure heating) per unit length for a four-vane RFQ linac. The rf current on the vane tip is relatively small, reaching a maximum (~9 kA/m, or ~6 times the surface currents in a drift-tube linac) at the vane base and resonator cavity wall. Schriber concludes that thin vanes and small resonator cavity i.d. are desirable to reduce the rf losses.

RFQ Resonator Design Considerations

A prime function of the RFQ resonator cavity is to provide an rf current path from one vane to another. The exact shape of the quadrant is relatively unimportant, but it is desirable to approximate a cloverleaf cross section. The circular geometry with the vanes having flared bases is a compromise, and was selected for the first high-power test (the 425-MHz RFQ POP experiment); however, the soft-copper structure was insufficiently rigid, and there were unacceptable dimensional deviations from designed values. The cavity could not be tuned except by physical deformation. This procedure required a fair amount of "art", because movement of one structural component shifted all other components of the cavity. When the deformation force was removed, the resonator cavity would relax into yet another configuration. Tuning required approximately four weeks of intense work.

Because most 400-MHz frequency range RFQ designs are 1.8 to 2.5 m long, and have an ~16-cm i.d. (insufficient for manual access to the cavity interior), assembly is complicated by the requirement that adjustments and other mechanical operations must be accomplished through external access holes. Vane-tip machining now is done easily and accurately with a one-piece steel vane that is copper plated by the leveling, bright-acid technique; this gives an excellent surface for rf currents, and the plating thickness can be adequately uniform in the tip region. As tuning experience has been acquired with RFQ linacs, it has become obvious that vane movement for tuning is essential to disconnect the rigid electric tolerance requirements from the mechanical tolerance requirements. A flexible vane-to-cavity rf joint allows the vane to be moved radially and rocked, but these joints are in the region of highest rf currents. Several methods have been proposed to make the vane-to-cylinder rf joint. An electron-beam weld is difficult because of the length of the cylinder and the small cross section. A laser weld cannot be done because copper is an efficient reflector of common laser wavelengths. A plasma-arc spray requires equipment too large to fit easily within the resonator cavity. A relatively low-temperature, vacuum; or hydrogen furnace braze produces acceptable rf joints, but braze runs may upset the cavity tune. A copper-plate rf joint, using solution plating, would be difficult in such a complicated geometry, and brush plating would be difficult in the confined space of the quadrant. In either case, a gap between the vane and the cylinder might prevent the copper plate from forming the continuous surface necessary for a good rf joint.

An rf joint formed by using a compressed soft-metal wire or ring is a technique used in many accelerator applications. There are three problems with this approach for a simple vane-to-cylinder rf joint: (1) good rf contact requires large compression forces, (2) surface irregularities might cause a nonuniform rf contact, and (3) the radial position of the vanes cannot be easily altered. Recent Los Alamos efforts in 400-MHz-region RFQ resonator-cavity design have concentrated on the development of flexible rf joints between the vanes and the cylinder.

Flexible RFQ rf Joint Designs

Several types of flexible rf contacts have been proposed that are compatible with the restricted space in 400-MHz-size cavities. One flexible rf joint design concept under development for 400-MHz-size RFQ resonator cavities is the C-seal joint. A cross section of the C-seal RFQ is shown in Fig. 4. It is a simple cylindrical cavity with each vane held in place by two rows of screws. Inconel C-seals (commercially available in a variety of sizes), plated with 0.005-cm-thick copper, are captured in the vane groove, making contact with the vane and the RFQ with a nominal 20% squeeze. This results in an ~66.9 kg/cm contact force. In theory, as the C-seal is squeezed, the contact points are forced outward from the vane, causing a highly localized contact force at the point where the rf currents must pass. Because the C-seal is compact, the rf-coupling slots are not unduly shortened. The radius at the contact point lessens the probability that the copper-plated surfaces will be damaged. The small surface area for rf current flow implies that the potential for heat-caused changes in the contact force is lessened. The good contact force allows the C-seal to adjust to minor cavity surface irregularities; also, the C-seal concept is very simple and inexpensive.

The other flexible rf joint under development for 400-MHz-size RFQ resonator cavities is the rf clamp-joint, shown in Fig. 5. This rf joint is made by two compression bars that force the soft-copper contact strips into contact with the copper-plated edge of the steel resonator-cavity cylinder. The 0.08-cm-thick copper contact strips are furnace brazed to the mild steel vane. The compression force on the contact edge can be up to 357 kg/cm--the normal design force on a wire vacuum seal. Assembly of the resonator cavity begins by placing the vanes in a nominally correct mechanical position in the cavity. The cavity is then tuned by slight movements of the vanes, and the compression bolts, are tightened until the cavity Q is satisfactory. Final minor vane movements and tuning

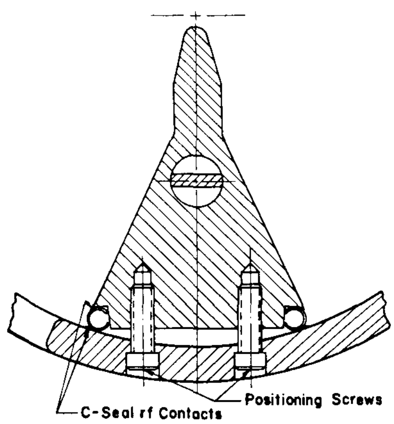

Fig. 4. RFQ with C-seal rf joints.

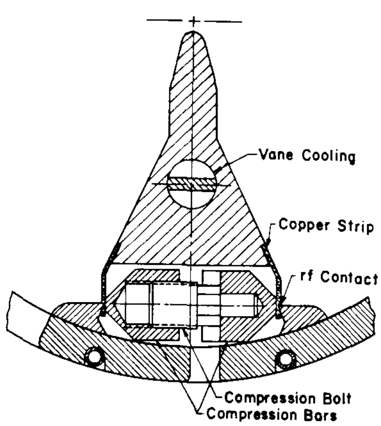

Fig. 5. RFQ with rf clamp-joints.

adjustments are made, with the flexible copper strips deforming as necessary to compensate for the revised vane positions.

RFQ rf Joint Tests

Four test cavities of essentially the same 400-MHz geometry were used to evaluate RFQ rf joints. Each cavity was an ~26-cm-long, ~15-cm-diam cylinder in which four vanes were mounted. The vanes were foreshortened; therefore, the actual resonant frequency was ~800 MHz. All components were copper-plated steel. Cavity 1 had the vanes furnace brazed in place to provide a benchmark for the remaining tests. Cavity 2 was used to evaluate wire seals of various materials. Cavity 3 was used to test the C-seal rf joints, and Cavity 4 was used to evaluate the rf clamp-joint. The results of these tests are summarized in Table I. These tests indicate that a good mechanical joint is achievable. The gold-to-gold joints all have a Q of ±6400; most copper-to-copper joints have a Q of ±4600. It may be that the surface conditions at the contact point are more important than the contact method or force. These joint tests are continuing.

Table I

RFQ rf JOINT TESTS

Cav. No.	rf Joint	rf Joint/Surface Material	Q
---	---	Theoretical	8500
1	Brazed	Cusil (72% Ag, 28% Cu)	6100 ± 305
2	Wire	Gold wire/gold	6400 ± 320
		Copper wire/gold	6400 ± 320
		Copper wire/copper	4400 ± 220
		Gold-plated copper wire/gold	6300 ± 315
3	C-seal	Copper-plated Inconel/copper	6000 ± 300
4	Clamp	Copper sheet/copper	4800 ± 240

Conclusions

The C-seal joint, using commercially available hardware, is the essence of simplicity, but it must make two rf contacts per joint, doubling the joint losses and the probability of an eventual contact failure. The positioning screws are under tension; relaxation of the screw threads will cause the vane position to change, altering the cavity tune. Also, the rf contact force is directly coupled to the vane position. The rf clamp-joint approach involves more machining than the C-seal; but the positive and vane-position-independent action of the rf clamp-joint may provide better long-term stability. For high duty-factor applications, the heat transfer with the rf clamp-joint copper strips may be an advantage over the copper-plated Inconel C-seals. Much has been learned about the tuning and technology of RFQ linacs. The search for a tunable design having long-term stability is still in progress, but the development of flexible mechanical rf joints promises to be an important technological advance in RFQ linac design.

Acknowledgments

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